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## **ARB LPG Fuel Blends Evaluation Project May 1998 Progress Report**

submitted to:

### **ARB LPG Fuel Blends Evaluation Project Task Group**

*American Automobile Manufacturers Association, ARCO Products Company, California Air Resources Board, Cummins Engine Company, Engine Manufacturers Association, Equilon, Ford Motor Company, GFI, IMPCO, National Propane Gas Association, Natural Resources Canada, Railroad Commission of Texas Alternative Fuels Research & Education Division, South Coast Air Quality Management District, Western States Petroleum Association*

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### **I. Executive Summary**

Fuel blends were delivered to the testing laboratories. ORTECH Corporation (ORTECH) completed baseline (certification) fuel, and test fuel #1 emissions tests. ADEPT continued to coordinate with Cummins and ORTECH on technical questions and issues. Dixie Services, Inc. (Dixie) completed the fuel properties and octane testing and submitted preliminary results. Solicitations for pre-proposals for performance/combustion tests and for durability tests were distributed to all appropriate candidate laboratories.

### **II. Test Program Work Performed**

#### ***A. Fuel Delivery to Current Subcontractors***

LPG fuels arrived at ORTECH for emissions testing on April 30<sup>th</sup>. The fuels first delivered to Dixie and subsequently to the ARB's Haagen Smit Laboratory (ARB-El Monte) were from the same cylinders. Aeriform shipped LPG fuel samples to Dixie. Dixie pulled samples of the fuel blends and then notified Aeriform that the cylinders were ready to be shipped to ARB's Haagen Smit Laboratory in El Monte, California (ARB-El Monte). The cylinders were shipped to ARB-El Monte on May 27<sup>th</sup>.

#### ***B. Fuel Properties and Octane Testing***

Dixie completed the fuel properties and octane testing of six fuel blends received from Aeriform. Preliminary results were submitted to the Technical Committee (TAC) on May 4<sup>th</sup>. The complete analyses of the LPG mixtures were submitted on May 29<sup>th</sup>. (See attached) Table #1 summarizes the fuel blends selected, the fuels delivered by Aeriform, and Dixie results.

Table 1: Fuel Properties

		Propane	Propylene	Butane <sup>1</sup>	Other (e.g. ethane)
<b>Materials ordered by ADEPT</b>	<b>Fuel (Cert.)</b>	93.5 ± 1.0 %	3.8 ± 1.0 %	1.9 ± 1.0 %	-
	<b>Test Fuel 1</b>	85 ± 1.0 %	10 ± 1.0 %	5 ± 1.0 %	-
	<b>Test Fuel 2</b>	80 ± 1.0 %	15 ± 1.0 %	5 ± 1.0 %	-
	<b>Test Fuel 3</b>	80 ± 1.0 %	10 ± 1.0 %	10 ± 1.0 %	-
	<b>Test Fuel 4</b>	76 ± 1.0 %	4 ± 1.0 %	20 ± 1.0 %	-
<b>Aeriform Claim for Materials Composition</b>	<b>Fuel (Cert.) – Cylinder 1</b>	94.248 %	3.839 %	1.913 %	-
	<b>Fuel (Cert.) – Cylinder 2</b>	94.257 %	3.835 %	1.908 %	-
	<b>Test Fuel 1</b>	84.96 %	10.02 %	5.02 %	-
	<b>Test Fuel 2</b>	79.984 %	15.01 %	5.0069 %	-
	<b>Test Fuel 3</b>	79.97 %	10.02 %	10.01 %	-
	<b>Test Fuel 4</b>	76.18 %	3.83 %	19.99 %	-
<b>Dixie's Reported Analysis of Materials Composition</b>	<b>Fuel (Cert.) – Cylinder 1</b>	94.05 %	3.73 %	2.20 %	0.02 %
	<b>Fuel (Cert.) – Cylinder 2</b>	94.07%	3.72%	2.19%	0.02%
	<b>Test Fuel 1</b>	85.26 %	9.58 %	5.11 %	0.05 %
	<b>Test Fuel 2</b>	80.23 %	14.60 %	5.12 %	0.05 %
	<b>Test Fuel 3</b>	80.02 %	9.79 %	10.15 %	0.04 %
	<b>Test Fuel 4</b>	76.12 %	3.71 %	20.13 %	0.04 %

<sup>1</sup> n-butane + isobutane

### C. Medium-Duty Engine (Cummins B5.9LPG) Emissions Tests at ORTECH.

Equipment issues on the gas chromatography (GC) speciation analyzer were resolved allowing for completion of quality control setup.

Emissions testing<sup>1</sup> began on May 19<sup>th</sup> on a Cummins B5.9LPG Engine (Serial #45406154). Three sets of baseline emissions tests on certification LPG fuel were conducted. Two sets of emissions tests were performed on test fuel #1 (summary emissions results in Table #2, complete results in attachments). Manual torque maps were completed for certification LPG fuel and test fuel #1. (See attachments) Audible knock verification was conducted for each manual torque curve (at each speed and load point audible knock was listed for). This work was conducted to insure that when the auto torque curve was used, no knock would occur. No knock was noted during the manual torque mapping process.

<sup>1</sup> Testing protocol is attached.

**Table 2: Preliminary Medium Duty Engine Emissions Results**

	Weighted Average of Emissions Tests (all values in g/bhp-hr) Includes hot and cold starts (complete results in attachments)							
Fuel Type	Work hp-hr	BSFC lb/hp-hr	NMHC	THC	CO	NO <sub>x</sub>	PM	CO <sub>2</sub>
Certification Set #1	11.87	0.518	0.849	0.884	0.418	2.779	0.006	670
Certification Set #2	11.89	0.52	0.811	0.847	0.329	2.765	0.006	680
Certification Set #3	11.90	0.521	1.045	1.083	0.369	2.921	0.007	675
Test Fuel #1 <sup>2</sup> Set #1	12.08	0.500	0.694	0.726	0.409	3.067	0.009	666
Test Fuel #1 Set #2	12.08	0.502	0.730	0.762	0.451	3.157	0.007	662

At this point in emissions testing there is insufficient data to make any firm conclusions about any of the test fuels passing emissions criteria.

On May 15<sup>th</sup> the TAC approved two ORTECH subcontract amendments:

1. Amendment Authorization #1, providing \$10,000 for the following three additional tasks: (1) daily engine performance check runs and torque / power corrections over a period of two weeks, (2) tests to determine ECU supply voltage vs. engine torque / power output, and (3) tests to determine the impact of ECU supply voltage on engine transient emissions.
2. Amendment Authorization #2 providing \$1,000 for a baseline transient emission tests on certification fuel after completion of the tests on fuel #2.

The above subcontract changes were approved in response to discoveries that ORTECH made during engine precalibration testing:

- a) The B5.9LPG engine emissions and performance change significantly with ECU voltage variations. Testing was conducted to establish a fixed ECU supply “testing voltage” and throttle control setting. Upon repeated consultations with ORTECH and Cummins, ADEPT established the test voltage at 13.25 to 13.35 volts. This was critical to the test protocol in that it enabled repeatability. However, since a test voltage was set, it does not precisely mimic a “real life” engine-on-the-road scenario where broader voltage variations will occur.
- b) Additional baseline emission tests on certification fuel will be conducted in June and July to ensure that no shifting occurs in the emissions performance of the test engine.

<sup>2</sup> Test fuel #1 (cyl. #73977): 85.28% Propane, 9.86% Propylene, 4.86% N-Butane

The TAC decided to use test fuel #2, delivered to ORTECH even though its propane content was 0.15% above the amount required in the specifications.

***D. Light-Duty Truck (F150 Bi-Fuel) Emissions Tests at ARB Haagen Smit Laboratory***

Ford was able to provide a Ford F150 truck (VIN #2FTRX17LOWCA49211 and engine family WFMXT05.45BF). The Ford F150 is a test vehicle built to production specifications. It is equipped with a bi-fuel gasoline and propane engine. The gasoline canister was disconnected and purged prior to certification / verification tests conducted at Ford Motor Company in Dearborn, MI. These tests were to verify that LPG emissions from the vehicle showed no evidence of gasoline effect and to check for consistency with other LPG emissions results.

The truck arrived at ARB-El Monte's laboratory on May 22<sup>nd</sup>. ARB-El Monte began light duty emissions testing on May 27<sup>th</sup>.

***E. Performance / Combustion Tests and Durability Tests***

ADEPT requested pre-proposals for Performance and Durability tests from five (5) laboratories: Colorado School of Mines (CIFER), Cummins, and ORTECH. Southwest Research Institute (SwRI), and the University of California Riverside Research Center (CE-CERT). The solicitation process will continue into June. The test protocol is being refined through a consultation process with the candidate labs.

**II. Project Management Support and Administrative Work Performed**

***A. Project Fundraising***

ADEPT submitted a funding proposal to the Engine Manufacturers Association (EMA) to cover additional costs for Cummins support of the project. Outstanding proposals to Exxon and Tosco are presently under consideration.

***B. Project Expenditures<sup>3</sup>***

Table 3 shows May expenditures and total expenditures in May.

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<sup>3</sup> New project outlays above \$1,000 are to be pre-approved by the TAC.

**Table 3: Funds Status**

<b>Item</b>	<b>Funds Expended In May</b>	<b>Total Funds Expended</b>
Fuel (Aeriform)	\$0	\$3,000
Emissions Tests (ORTECH)	\$0	\$42,000
Fuel Properties (Dixie)	\$0	\$0
ADEPT P.M.	\$6,423.49	\$6,423.49
Attorney Fees	\$0	\$2,250.00
Subcontractor	\$0	\$473.29
Miscellaneous	\$17.74	\$17.74
<b>Total</b>	<b>\$6,441.23</b>	<b>\$54,164.52</b>

Project Account Balance as of May 30, 1998: \$1,555.48

Total funds received to date, by funder source are:

<b>Funder</b>	<b>Amount</b>
NPGA	\$8,920
Shell	\$36,000
WPGA	\$10,800
<b>Total</b>	<b>\$55,720</b>

**C. Project Contracts and Other Documents**

Except for Cummins, ADEPT has received all signatures for the MOU filing. The NPGA, PGAC, SCAQMD, Shell, WPGA funding contracts are complete. The AFRED, ARB, ARCO, Cummins and Ford contracts are in various stages of completion. The Disclosure of Joint Research Venture Filing awaits letters from ARB, AFRED, NRCAN, and Cummins.

Other project administration activities conducted by ADEPT in May included: monthly report preparation; weekly conference calls with ARB; assembly of conference call materials for TAC and Task Group conference calls; contact list preparation and distribution; and funding contract drafting and revisions.

The ARB hosted a Task Group conference call/meeting on May 20<sup>th</sup>.

NREL completed abandonment of the test engine to ADEPT. This engine is undergoing emissions testing at ORTECH.

**Travel associated with effort described:**

No travel was conducted on behalf of the project.

## **II. Work planned for the next reporting period (June 1 - 30, 1998)**

### **Project Management-ADEPT**

1. ADEPT will continue general project management.
2. ADEPT will prepare and complete funding contracts and letters of agreement for co-sponsors.
3. ADEPT will continue fundraising.
4. ADEPT will review pre-proposals for performance/combustion tests.
5. ADEPT will solicit and review final proposals for performance/combustion tests from qualified labs.
6. ADEPT will prepare materials for the TAC to evaluate the qualified laboratories' proposals to conduct performance and combustion testing.
7. ADEPT will recommend to the TAC and the Task Group one qualified laboratory to conduct the performance and combustion tests.

### **Test Program**

1. ORTECH: Continue emissions testing.
2. ARB Haagen Smit Laboratory: Continue Light Duty Emissions Testing.

## **III. Attachments:**

1. Project Timeline (GANTT Chart).
2. Dixie Fuel Properties and Octane Testing results.
3. ORTECH Weekly/Interim reports.
4. Manual Torque Maps from Emissions Testing at ORTECH.
5. Medium Duty Emissions Testing Protocol

## **IV. Disclaimer**

This report was prepared by The ADEPT Group, Inc. (ADEPT) as a result of work co-sponsored by the California Air Resources Board (ARB) and the Task Group Members. The opinions, findings, conclusions, and recommendations are those of the author and do not necessarily represent the views of ARB. ARB, their officers, employees, contractors, and subcontractors make no warranty, expressed or implied, and assume no legal liability for the information in this report. ARB has not approved or disapproved this report, nor have they passed upon the accuracy or adequacy of the information contained herein.

## **V. Glossary of Acronyms**

ARB	California Air Resources Board
bhp	brake horse power
BSFC	brake specific fuel consumption
C	Celsius
CO	carbon monoxide

CO <sub>2</sub>	carbon dioxide
CE-CERT	University of California Riverside Research Center
ECU	electronic control unit
EMA	Engine Manufacturers Association
F	fahrenheit
g/bhp-hr	grams/brake horse power/hour
Hg	mercury
kPa	kilopascals
lb.-ft.	pound feet
LPG	liquefied petroleum gases
NMHC	non-methane hydrocarbons
NO <sub>x</sub>	oxides of nitrogen
psig	pounds per square inch of gas
ppm	parts per million
rpm	revolutions per minute
SwRI	Southwest Research Institute
TAC	Technical Assessment Committee
THC	total hydrocarbons